Final Report

Project Title: PV Charging System for Remote Area Operations

Covering Period: March 16, 2006 to June 30, 2008

Date of Report: July 31, 2008

Recipient: Argon ST, Inc. (formerly Coherent Systems International, Corp)

Award Number: DE-FG36-06GO86075

Working Partners: American Electric Vehicles

Cost-Sharing Partners: American Electric Vehicles

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Project Objective

To provide the public with a study of new as well existing technology to recharge batteries used in the field. A new product(s) will also be built based upon the information ascertained. This requires a system that will provide electrical energy in remote locations independent of re-supply lines. This need leads to the requirement for a lightweight, portable system that uses the available environmental power and transforms that into DC power for batteries. Solar energy is one source that, although not continuous, is available worldwide and is reliable when available.

Project Overview

In the wake of the Global War on Terror (GWOT) and recent natural disasters, it has become obvious that first responders, forest fire fighters, and military forces depend heavily on battery-operated equipment to perform their missions. The need to recharge their batteries is paramount for success, but requires a system that will provide electrical energy in remote locations independent of re-supply lines. This need leads to the requirement for a lightweight, portable system that uses the available environmental power and transforms that into DC power for batteries. Solar energy is one source that, although not continuous, is available worldwide and is reliable when available.

Unfortunately, current solar cells are hampered or severely limited by cloudy conditions. Traditional solar cell performances are limited to specific internal radiance thresholds. If radiance is not sufficient, then the solar cells do not work. For a solar system to be effectively used by the first responders and military personnel, development of a charging system that allows solar cells to operate at greatly reduced radiance levels is necessary.

Approach: Development of a state-of-the-art integrated PV system Goals versus Accomplishments

American Electric Vehicles, Inc. (AEV) developed systems and methods suitable for charging state-of-the-art lithium-ion batteries in remote locations under both ideal and cloudy weather conditions. AEV's work was conducted as follows:

1. Requirements Definition. - Completed
2. Identification of Required Technologies. – Completed
3. Conceptual Design Based on Existing Technologies. – Completed
4. System Integration, Test, and Validation. – Completed
5. Conceptual Design of Next-Generation System. - Completed

Deliverables

Reporting requirements per the contract are:

1. Requirements Document
2. Concept Design Document, Existing Technology
3. Prototype Systems Test Report
4. Conceptual Design Document, Next Generation Technology
5. Periodic Reporting – Once per Quarter

The periodic reports #1 - #6 per item 5 above were delivered and will not be included herein. Items 1 through 4 follow as a brief discussion of the information contained in detail in the progress reports.

Requirements

Disaster reports for hurricane Katrina, hurricane Rita, the South Asia [Kashmir 2005] earthquake, and the Indonesian [2004] Tsunami were studied to glean information about response requirements and needs. The International Association of Emergency Managers [IAEM] conference and exhibition provided insights into the operation of emergency management personnel and equipment being provided by industry. Discussions with the "Global Volunteers Network" provided further information on the operations and needs outside the United States. Discussions with U.S. Forest Service personnel provided a unique view of potential uses of off-road, remotely chargeable electrical transportation within the U.S. Forest Service areas. General forest maintenance requiring remote area transport and remotely powered fire watch cameras with wireless image transmittal.

Common themes emerged; health concerns, food and drinking water supplies, communications, transportation, and shelter were at the top of the list. Power to generate clean drinking water, provide for command and control, communications, lighting for shelters, power for health clinics, and fuel for transportation were required in all of the natural disasters reviewed. Requirements for disaster mitigation and socioeconomic restoration in the first days of a disaster lie with providing power to sustain life and support the equipment.

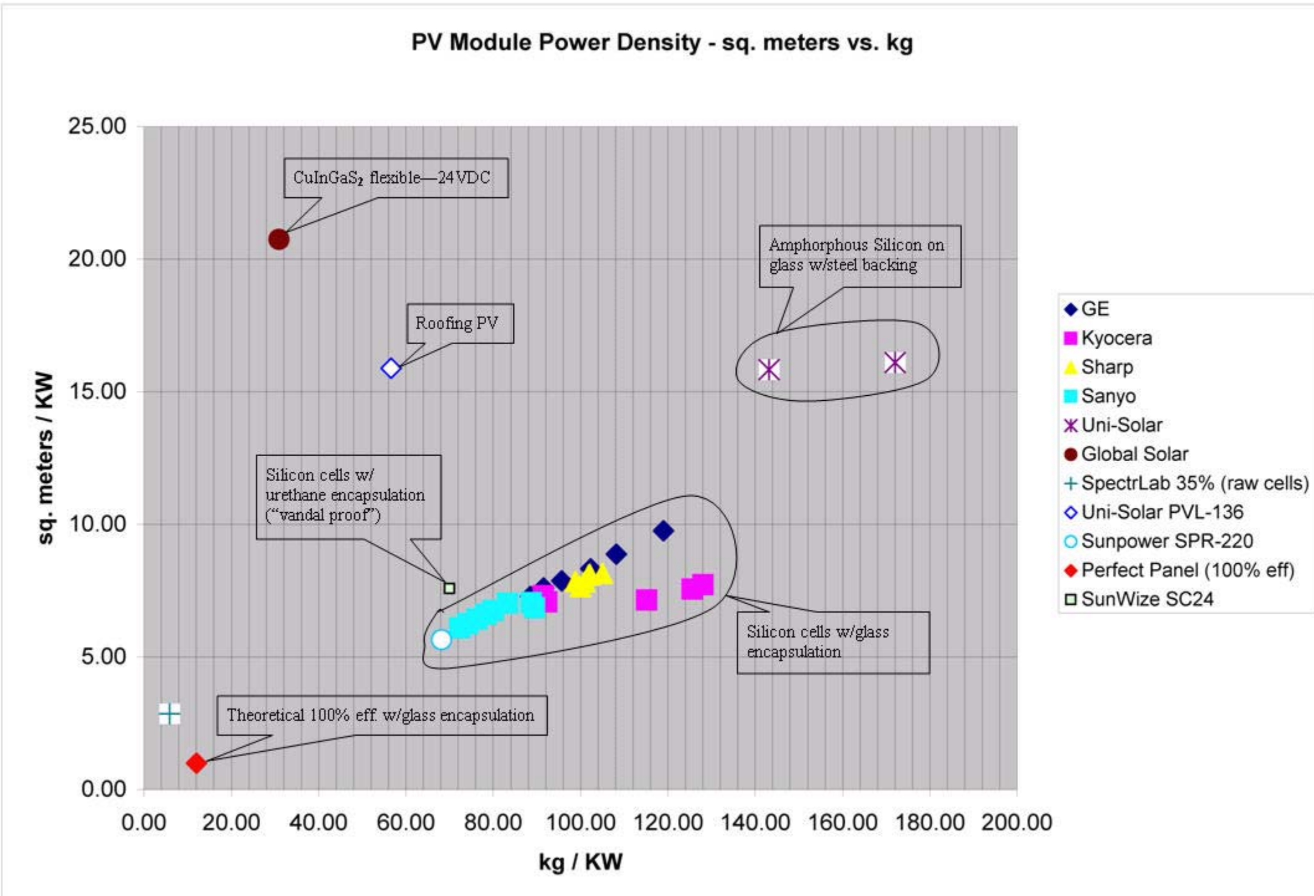
Small power generation units for water purification, light emergency medical equipment, and lighting would be extremely beneficial during the aftermath incident.

Public lands maintenance and natural disaster mitigation were the foremost interests for the U.S. Forest Service.

Solar energy collection applied in the remote and first responder applications requires high efficiency energy conversion, energy storage, and durability, must be lightweight, and must be easily transportable.

Concept Design Document, Existing Technology

Solar Cells



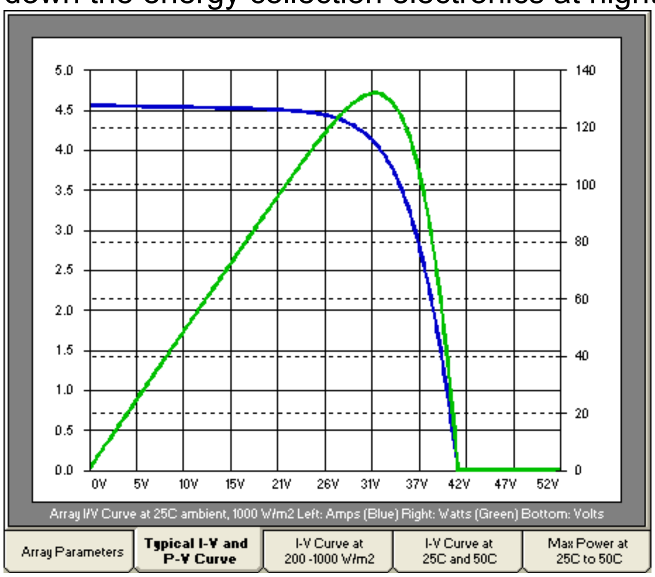
The above graph shows the different solar technologies with respect to the power density. The best technologies would be found in the lower left corner of the graph. The 35% efficient cells cost about $300/Wp and are difficult to obtain. Monocrystalline silicon solar cells are readily available at a cost of about $5.00/Wp on a glass encapsulation. Glass is not appropriate for lightweight, portable applications. Monocrystalline silicon solar cells, and a urethane encapsulation with an F4 fiberglass substrate provided rigidity, durability and a 15% energy conversion. This construct allows for the substitution of 35% triple junction cells to more than double the energy conversion.

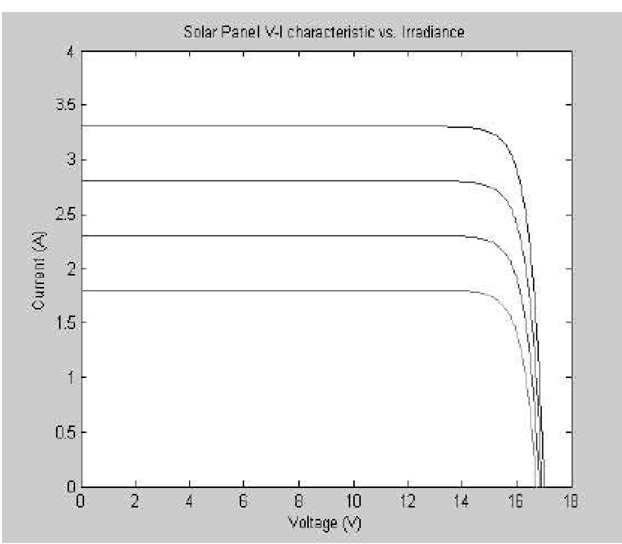
This is the construction concept for the primary energy conversion means.

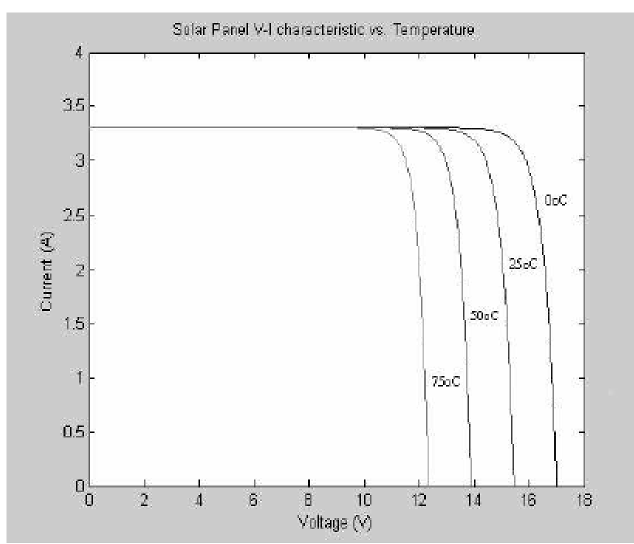
Peak Power Trackers

Two fundamental external influences affect the solar panel power output; temperature and solar insolation. Under ideal conditions the solar panel will convert a portion of the available energy based on the solar cell efficiency alone. The efficiency, however is directly affected by the cell operating temperature which causes the peak power point (green line) to shift to the left or right and the solar panel output to increase or decrease. Insolation changes cause a minor shift in the peak power point. It is desirable to maintain the solar panel operating point at the maximum power point, i.e. the peak of the green line, throughout temperature swings and changes in insolation. The impedance matching requires control circuitry that monitors the peak power point and adjusts the amount of power drawn from the panel to maintain the optimal operating point, thus maximizes conversion efficiency.

A very low tare load peak power tracker is required to maximize the energy conversion efficiency. Low tare power can be achieve by using low power draw circuitry and shutting down the energy collection electronics at night.





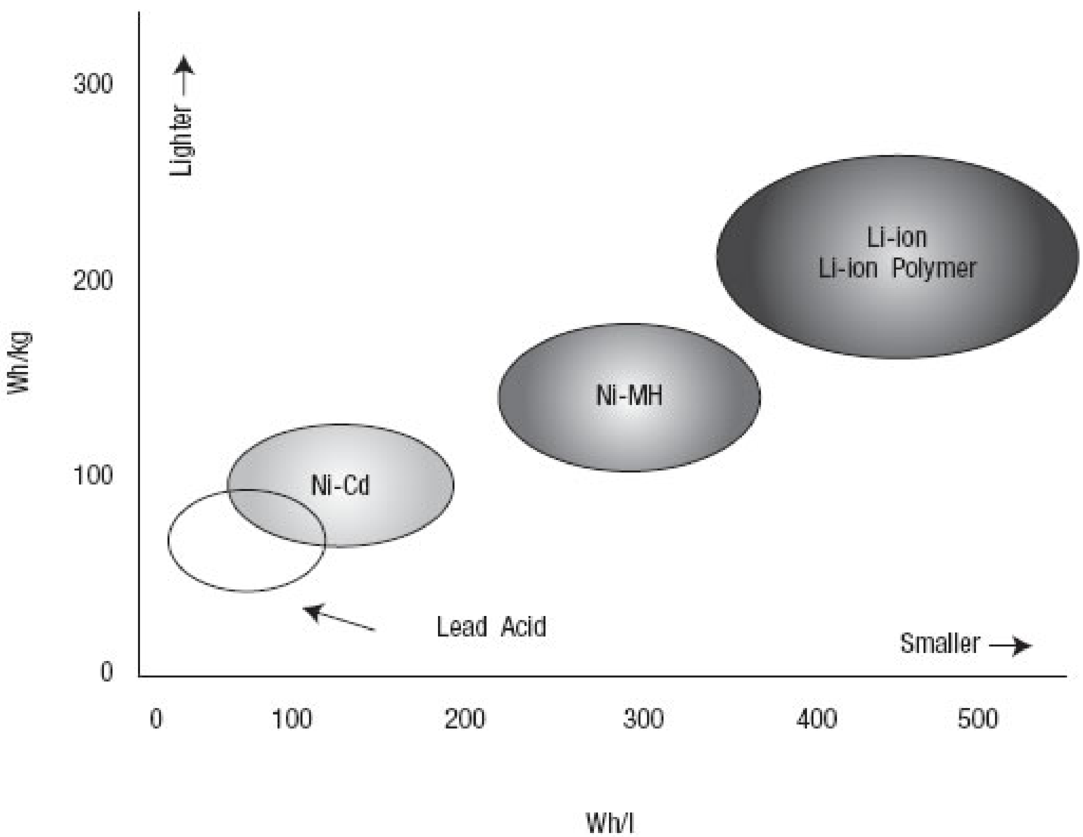


Batteries

Energy storage is a requirement to provide power during the night and be a buffer for momentary or extended excess power draws. The graph below shows the characteristics of the different battery technologies considered. Lithium ion technology is clearly the battery of choice for the small, lightweight applications. Lithium ion also has an extremely low self discharge rate.

Lithium ion battery technology is the preferred storage medium.

Figure A4.1. Comparison of Energy Density of Various Small, Sealed Battery Systems



Prototype Systems Test Report

Solar Power Pack – 1st Generation

24 Wp solar panel w / low power peak power tracker
480 Wh lithium ion batteries
Unitized package

The battery pack with electronics was packaged behind the solar panel. Temperatures upwards of 60°C were measured on occasion internally in the battery/electronics cavity. While the unit performed well for the U.S. Forest Service, a 2nd generation design was done to separate the solar cell and battery/electronics to ensure long battery life and proper circuitry operation. An insulated enclosure could then be used around the battery/electronics unit.

Solar Power Pack – 2nd Generation

Rugged urethane encapsulated solar panels fold in four sections in a canvas covering to produce a compact hand carried unit. The battery with electronics is in a separate unit that can be insulated in a canvas carrying bag.

The system calculations show the ability for the unit to recharge a completely discharged 1KWh battery in 6 days. The 1 KWh battery pack allow for excess current draws while the solar panel can be used to recharge the battery slowly over time. The unit features the identified important component: a durable high efficiency solar panel, solar panel peak power tracking, and a reasonable amount of energy storage in a lightweight mobile package.

Portable Power Pack

A portable, rugged, rechargeable power unit for remote locations with both D.C. and A.C. power outputs.

1KWh lithium ion battery
26Wp durable solar panel
Battery Management electronics with solar peak power tracker
12VDC output
110VAC / 300 watt output / sine wave
Wall charger for pre-charging the battery
Water proof case
Weight: 31 lbs.

We would have liked to send this unit to the U.S. Forest Service for testing, but the project termination and their fire monitoring schedule do not allow that testing to be done.

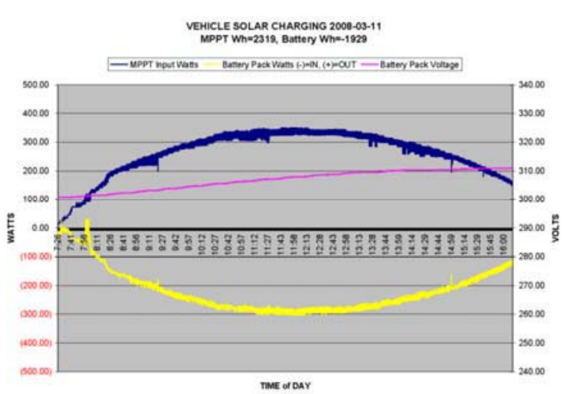
Solar Recharged Electric Off-Road Vehicle

Energy collection on a sunny day in Colorado:

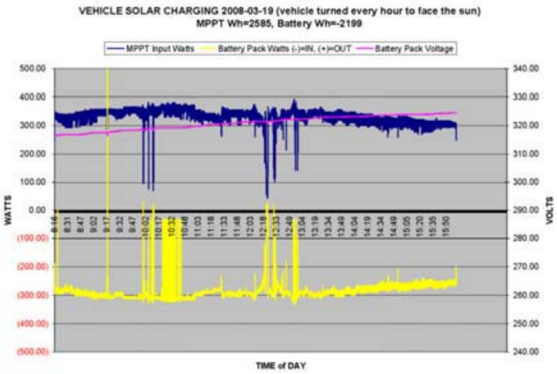
Vehicle stationary – additional 4.8 – 6.4 miles of operation with 15.8% of the battery pack being recharged in a single day.

Repositioning the vehicle every hour, the solar power capture provided an additional 5.5 – 7.3 miles of operation with 18% of the battery pack being recharged in a single day.

350 watts of rugged solar panels
95% efficient peak power tracker
12.2KWh lithium ion battery pack



The key points of this system are the very high performance peak power tracker with conversion efficiency near 95% on the system level and the rugged silicon wafer based solar panels. The solar panels have a urethane coating with a thick micarta backing. The solar panel construction is lightweight and extremely durable. Materials and equipment can be load on the panels when they are in the flat, stowed position. With full sun the 12.2 KWh battery pack can recharge in 5 days.



The maximum peak power tracker (MPPT) utilizes advanced design techniques with the latest components to achieve the exceptional performance. Power device commutation near zero current combined with low loss magnetic components in the converter section allow for maximum (>98%) conversion efficiency under nideal conditions.

This recharging capability allows for vehicle autonomy without fossil fuels.

Conceptual Design Document, Next Generation Technology

Solar cells -

The panel fabrication schemes were designed so that the advanced triple junction cells could be used. It was not prudent to use those cells on this project due to price considerations. SpectroLabs has now made 40% efficient triple junction cell which would more than double the power collection capabilities of all the specific applications demonstrated.

Solar Panel Peak Power Tracker -

Low power CMOS circuitry was employed throughout and the microprocessor was in low power sleep mode at night and during some states. Circuitry for the solar panel power conversion to battery charging used MOSFETs. The MOSFETs and associated gate drive circuitry are the largest tare load in the electronics. MOSFET technology continues a rapid development with lower on resistance, lower gate charge requirements, and faster switching times which equates to lower power consumption to provide the required power switching. This is the prime development area for future improvement.

Batteries –

Development of lithium batteries will continue with improvement in energy density. The electric vehicle industry will drive the continued development. Zinc-Air technology currently used in hearing aides could possibly be developed into large scale rechargeable cells, although little or no work is being done in the scale up of these cells.

General Project Closeouts Notes -

No inventions or patentable items were produced.

No Government furnished property was acquired.

See attachment for the materials acquired with project cost share funds.

Major Task Schedule

Task Number	Task Description	Task Completion Date				Progress Notes
		Original Planned	Revised Planned	Actual	Percent Complete	
1	Requirements	10/31/06	NA	10/31/06	100	
2	Review of Technology Base	1/15/07	NA	1/15/07	100	
3	Formulate Concept Designs	8/31/07		12/7/06	100	
4	Concept Design Analysis and Performance Prediction	9/30/07		3/7/07	100	
5	Rank Concepts versus Requirements	10/31/07		3/7/07	100	
6	Subsystem Detailed Requirements	6/15/07		6/7/07	100	
7	Design/Purchase/Build Subsystems	7/31/07		6/7/07	100	
8	Integrate Subsystems	9/30/07		6/7/07	100	
9	Test Subsystems	12/31/07		9/30/07	100	
10	Test Report	1/31/08		12/30/07	100	
11	Review of Next Generation Technologies	8/31/07		3/31/08	100	
12	Concept Design Analysis and Performance Prediction	12/31/07		5/1/08	100	
13	Sort Versus Requirements	1/15/08		5/1/08	100	
14	Next Generation Road Map	2/29/08		5/1/08	100	